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THE FUNCTIONS OF THE BLOOD.

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Every one who has looked through a microscope at a drop of blood, knows that the red or purple colour is confined to certain minute discs, which resemble pieces of money in form, and which float in a clear yellow liquid. The discs are known to physiologists as the *blood-corpuscles,* and the liquid as *liquor-sanguinis.* Both these constituents of the blood have their own specific functions to fulfil in the operations of life, and both have been the subject of numberless researches. Very much still remains to be done; but it is not too much to assert that this most wonderful of liquids is slowly yielding up its secrets to the patient workers who have so long sought for them in vain, and that "the blood, which is the life" of the animal, is no longer the utter, hopeless mystery which it has for ages remained.

Careful microscopic measurements have been made of the size of the corpuscles in the blood of different animals, and it is now generally agreed that in the human subject their average length is 1-3200th of an inch, and their thickness 1-12400th of an inch. Hence it would be possible, if they were packed close together, for 8,126,464 to lie in the compass of one cubic millimetre—a space not larger than a good-sized pin's head. Now the corpuscles occupy, in the aggregate, about one half of the volume of the blood,* and we are, therefore, able to form a good guess at their probable number. Vierordt and Welker have, indeed, gone through the laborious process of counting them; and the former fixes their number at 5,069,000, and the latter at 4,600,000, in the cubic millimetre. It will be seen that these figures agree tolerably well with the rough calculation founded on the size of the corpuscles, and we are, therefore, forced to admit that the tiny red drop obtained from the finger by the prick of a needle, may contain four or five millions of these curious bodies. Such figures, however, give but vague ideas to the mind. A more distinct one is, perhaps, conveyed in the fact, that a room sixty feet long, thirty feet wide, and fifteen feet high, could not contain as many grains of corn as there are corpuscles in a single teaspoonful of human blood, the number being, approximately, eighteen thousand millions!

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* This is, of course, only a rough approximation. Their quantity varies extremely in different parts of the body, and even at different times of the day.

that of the earth, as would probably be the case from its having nearly the same axial velocity, we could not hope to perceive it, for, under such circumstances, the flattening of the disk of Mars would not exceed twelve miles, and this when the planet is nearest to us, would subtend an angle of only one-tenth of a second.

Professor Phillips's drawings of Mars, of which three are engraved in the "Proceedings of the Royal Society," No. 55, were taken when the north pole of Mars was invisible. Allowing for the difference produced by this cause, the drawings agree with mine in the general form of the markings, but the white margin which I only see in the bays, Professor Phillips shows completely fringing the whole of the markings.

Now half a second is the smallest amount of difference in diameter we could hope to detect, even by the aid of the most delicate micrometric apparatus. The double-image micrometer, devised by the Astronomer Royal, would be the best to employ for this measurement.*

No satellite attending on Mars has yet been discovered. Pursuing the analogy between the planet and our earth, if such a satellite existed of a size proportionate with our moon, as it would be one-quarter the diameter of the primary, we might expect it to be easily visible, but should a satellite exist, not exceeding in size proportionately the second satellite of Jupiter, it would only be visible in very powerful instruments, still it would not, I think, have escaped the notice of the persistent observers who have searched for it hitherto vainly.

The discovery of a satellite to Mars is looked for with interest, as the effect of the sun and the primary in producing perturbations of a satellite would enable the density and mass of the planet to be accurately calculated. At present these are only imperfectly known, but the density is considered to be almost exactly the same as that of the earth.

Unfortunately, observations of value can scarcely be made upon this difficult planet with telescopes of less than six inches aperture, and, unless the observer has extremely good sight, eight or ten inches will be found necessary. During the next opposition I hope to be able to continue my observations with an instrument having a silvered glass speculum twelve inches in diameter.

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* In measuring, micrometically, the diameter of Mars, it is very difficult to avoid obtaining too large a result for the polar diameter, the effect of the irradiation causing the white spots near the poles to appear to project slightly from the disk of the planet. The best method, probably, of overcoming this difficulty is by using a single reflecting solar eye-piece.

It is still doubtful whether the corpuscles consist of red liquid, enclosed by a membrane, or whether they are semi-solid, and of uniform structure throughout. Two of the latest investigators, Max Schultze and Ofsiannikof, assert directly opposite opinions upon this point. Whatever they be, however, it is at least certain that they possess a definite term of life. They are incessantly being formed in the chyle and lymph, and also probably in the liver and some other glands. And after the completion of their work, they disappear or are destroyed, this destruction being seen most remarkably in the liver, and in the blood which has traversed muscular tissue.*

The chief function of the blood-corpuscles in the body has long been known, or, at any rate, strongly suspected. They are the carriers of oxygen, the agents of oxidation, in the animal body. During its passage through the lungs, the blood, as every one knows, loses carbonic acid and takes up oxygen. Every 100 volumes of the blood which enters the lungs is capable, according to Claude Bernard, of absorbing twenty-one volumes of oxygen. This is about seven times as much as an equal quantity of water could dissolve, and Berzelius, long ago, showed that serum, which differs but slightly from liquor-sanguinis, was hardly superior to water in this respect. Consequently, it is evident that the great mass of the oxygen must be attracted by the blood-corpuscles. The corpuscles, as before mentioned, constitute about one-half of the bulk of the blood, and, therefore, allowing for the small quantity dissolved by the liquor-sanguinis, we find that they absorb thirty-nine per cent., or thirteen times as much oxygen as water could. That this oxygen is combined in, and not merely dissolved by, the corpuscles, is indicated by the fact observed by Bernard, that pyrogallic acid, a substance that combines eagerly with free oxygen, when it is injected into the veins, will pass out of the body of the animal without undergoing oxidation. It has, therefore, been generally assumed, although upon imperfect proof, that the colouring matter of the corpuscles was capable of combining with oxygen in the lungs, and afterwards of giving that oxygen out again—in small doses, as it were—to the substances to be oxidized. This notion has been recently raised to the dignity of a theory by some beautiful experiments which physiology owes to a physicist—Professor Stokes, of Cambridge. Stokes's researches appear hardly to have received from physiologists the attention they deserve, and I, therefore, venture to present a brief description of them here. Hoppe-Seyler had previously recorded the curious fact, that when a ray of white light passes through a weak solution of blood, and is afterwards decomposed by a prism, two dark bands make their appearance in the green portion of the spectrum. Stokes repeated and verified the fact, and it soon became in his hands the starting-point of a new train of research.

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* Bernard, "Liquides de l'Organisme," i. 460.

He treated a solution of blood-corpuscles with an alkaline reducing agent, and observed that its colour almost instantly changed from scarlet to purple-red, the hue of veinous blood. On examining the spectrum, he now found that the two dark lines had disappeared, and that a single line, intermediate in position between them, had become visible. On shaking the tube with air, the scarlet colour and the two lines at once returned, but, after a few minutes, again disappeared; and this could be repeated many times. Hence it was evident that the scarlet arterial blood lost its oxygen to the reducing agent, and subsequently recovered it again, when shaken, from the air. The fact is so important that I prefer to give it in Stokes's own words. He says,—

"The colouring matter of blood, like indigo, is capable of existing in two states of oxidation, distinguishable by a difference of colour, and a fundamental difference in the action on the spectrum. It may be made to pass from the more to the less oxidized state, by the action of suitable reducing agents, and recovers its oxygen by absorption from the air."*

Hoppe-Seyler had shown that this colouring matter is different from the so-called *hæmatin,* which is obtainable by artificial means from the blood, and Dr. Sharpey therefore suggested that the true colouring matter should be named *cruorine.* The name is a good one, and does not, like "hæmato-globulin," which is adopted by Hoppe-Seyler, involve any hypothesis. In the oxidized—the scarlet state—it is distinguished as *scarlet cruorine,* and in the reduced state as *purple cruorine.* It is hardly necessary to point out how intelligible an explanation these facts afford of the oxygen-carrying power of the blood-corpuscles. In the lungs the purple cruorine of veinous blood takes up oxygen, and becomes scarlet cruorine; and in the whole of the general circulation, but more particularly in the capillaries, oxidation is effected by means of this oxygen, and the cruorine, to a great extent, passes back to the purple state. Hoppe-Seyler has since found that the blood of a rabbit which has been killed by drowning exhibits the spectrum of purple cruorine. In ordinary states, however, even veinous blood retains enough unreduced cruorine to give the two-line spectrum.

But Stokes has discovered another fact which is of extreme importance in regard to the question of animal oxidation. He found that a solution of the blood-corpuscles from arterial blood—a solution, that is, consisting mainly of scarlet cruorine—when excluded from the air, slowly *reduced itself,* and showed, after a time, the purple colour and the one-line spectrum of purple cruorine. On opening the tube and shaking it with air the scarlet colour returned, and with it the two-line spectrum. Hence it is clear that scarlet cruorine is capable of oxidizing a portion either of its own substance or else of the serum, from which it is impossible wholly to free it in the experiment. Whichever it be, it certainly is a part of the blood itself which is oxidized by the cruorine; and this fact is, as we shall presently see, in perfect accord with the theory to which we are led by other considerations.

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* "Proceedings of the Royal Society," vol. xiii. 357.

These curious optical experiments, apart from their physiological interest, have already yielded some practical results of considerable importance. Soon after the publication of Stokes's memoir, Mr. H. C. Sorby contrived an ingenious adaptation of the spectroscope to the microscope, and by its means succeeded not only in repeating all Stokes's experiments, but also in furnishing medical jurisprudence with a new and most valuable means of identifying blood-stains. The spectrum-microscope has since but somewhat improved in construction, and many readers of this journal have no doubt seen it, and the beautiful experiments which its inventor performs with it at some one of the recent scientific *soirées.* It is described in detail in a paper by Mr. Sorby, read before the Royal Society, April 11, 1867. A scrap of blood-stained fabric, 1-10th of an inch square, containing possibly not more than 1-1000th of a grain of colouring matter, may be experimented upon by its means, and the most certain evidence of the nature of the colour obtained. It has already been found useful in criminal trials.

Another interesting application of the spectroscopic examination of blood was made by Hoppe-Seyler. Claude Bernard discovered, some years ago, that the poisonous action of carbonic oxide gas was due to the circumstance that it had the power of displacing all the loosely-combined oxygen from the corpuscles, and of occupying its place in a somewhat more stable form of combination. All blood, veinous as well as arterial, after treatment with carbonic oxide, acquires a uniform red tint, which it retains with singular persistency, being, in fact, as Bernard expressed it, *mineralized* by the gas. Hoppe-Seyler submitted some of the blood so treated to optical examination, and found that it gave a spectrum very similar to, but not identical with, that of scarlet cruorine. But when excluded from the air, instead of reducing itself like scarlet cruorine does, it remained unchanged for an indefinite period of time. Hence the process indicated a delicate and certain test for use in cases of suspected poisoning by carbonic oxide. I myself, in ignorance of Hoppe-Seyler's experiments, made the same observations. I have by me now a sealed tube, which has for more than a year contained a solution of blood through which carbonic oxide had been passed. The spectrum has not altered in the slightest degree.*

To return from this digression, it is clear that we are now acquainted with the mode in which oxidation is effected in the body, as far as the earlier stages go. Oxygen is absorbed in the lungs, combines with the cruorine, and is afterwards given out again. But at this point we are compelled to pause to consider two more complex and exceedingly important questions. These are, firstly, What is oxidized? and, secondly, Where is the oxidation effected? Liebig, as everybody knows, divided the substances oxidized in the body into two great classes, corresponding with the chief constituents of food. These were the non-nitrogenous, or "respiratory" elements, and the nitrogenous, albuminous, or "plastic" elements. The former embraced fat, sugar, starch, etc., and all its members were supposed by him to be oxidized in the blood, and to evolve no force but heat as the result of their combustion. The latter consisted of the organized tissues, and in particular the muscular tissue, the oxidation of which chiefly resulted in the production of mechanical work. It is an obvious corollary from this hypothesis, that the oxidation of a solid tissue must be effected in the tissue itself, outside the walls of the capillaries, and we are therefore compelled to believe in two distinct modes of oxidation. Substances in the blood are in direct contact with the corpuscles, and may therefore be supposed to unite directly with the oxygen of the scarlet cruorine; whereas, for the direct oxidation of a tissue, it is necessary to assume that some of the oxygen leaves the corpuscles, traverses the walls of the blood-vessels, and arrives at the comparatively distant fibres in a state of solution, but in an uncombined condition. In its extreme form, Liebig's hypothesis has long been known to be untenable, for it cannot be doubted that nitrogenous substances, as well as non-nitrogenous ones, are oxidized in the blood, and contribute to the animal heat; and it has recently been demonstrated by the conjoined efforts of Traube, Heidenhain, and Donders, and still more distinctly by Fick and Wislicenus, Frankland and Parkes, that the oxidation of nitrogenous substances cannot account for nearly all the work done in the body. Traube, indeed, has started a rival hypothesis, which has been accepted by Fick and Wislicenus in their celebrated memoir;* namely, that the oxidation of muscle contributes nothing whatever to muscular power, but that the whole of the latter is derived from the oxidation of non-nitrogenous bodies, such as fats and the so-called hydrates of carbon. But as they agree with Liebig in placing the seat of this oxidation in the tissue, there is no great difference, as far as the blood is concerned, between the two views.

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* I believe reduced cruorine to be the most delicate, as it certainly is one of the simplest, qualitative tests for oxygen known. If a weak solution of blood is inverted in a test tube over mercury, it reduces itself in a day or two, and a small prism will then show the one-line spectrum. The minutest trace of oxygen will now restore the original spectrum; a single drop of distilled water will often contain enough. I obtained incidentally in the above experiments a confirmation of the previously known fact, that carbonic oxide is disengaged during the absorption of oxygen by potassic pyrogallate. Air from which the oxygen had been removed by this re-agent, when added to reduced cruorine, caused the latter to give a two-line spectrum, which lasted for weeks.

But are there, indeed, two distinct kinds of oxidation going on in the body, one inside and one outside the walls of the blood-vessels? Is it probable, or indeed possible, that sufficient oxygen can pass out through the thin walls of the capillaries to account for the enormous force exerted by the body in twenty-four hours? Mayer thought not, and argued against the notion in his immortal treatise, "Organic Motion in its connection with Change of Matter," published more than twenty years ago.† I believe he was right in this, as in so many other things, and I have elsewhere‡ drawn attention to his arguments, and endeavoured to add others to them. The question is one of immense theoretical and practical importance, and I will therefore enter into it in some detail.

To begin with, it is necessary to bear in mind another well-known and most important function of the blood. All the tissues of the body, the muscles among the number, are subject to a ceaseless process of disintegration and destruction. The elementary parts of which a tissue consists, have a definite term of life. They are born, grow, decay, and die, having previously developed new germinal matter from which their successors arise. There is no doubt about this, and it is equally certain that the nutrient matter, the *pabulum*, from which the new parts are formed and nourished, is derived from the blood, some portion of which must travel through the thin walls of the capillaries, and irrigate the tissue. Extreme uncertainty exists as to the mode in which this exudation takes place. At first sight it would appear to be simply a question of liquid diffusion; but, apart from the colloidal nature of the albuminous bodies of the blood, there are some striking points of difference between the composition of the blood and that of the muscular juice, in respect even of some of the most diffusible substances. Thus common salt, an extremely diffusible compound, is found in large quantity in the blood, but is almost entirely absent in muscular juice, and the blood is invariably and necessarily alkaline; whereas the liquid of the tissue is acid, and may even contain, as Liebig has remarked, enough acid to neutralize the blood. Probably the pressure under which the blood flows, influences in some manner the exudation, but it would be vain to pretend that it explains it.*

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* "On the Origin of Muscular Power," "Phil. Mag.," June, 1866 (Supplement).

† "Die Organische Bewegung in ihrem Zusammenhange mit dem Stoffwechsel." Heilbronn, 1845.

‡ "Phil. Mag.," May, 1867.

The excess of the nutrient fluid, together with the products of the disintegration of the tissues, returns to the blood, a portion perhaps direct to the capillaries, but the great bulk, in all probability, through the lymphatics, which seem to act as overflow-pipes to the tissues. Mayer therefore suggested that the quantity of lymph might be taken as a measure of the quantity of fluid exuded in a given time. Bidder and Schmidt estimate the lymph returned to the blood in twenty-four hours at 22 lbs., but it is safer to assume it to be at least 30 lbs. It would hardly do, however, to take even this quantity as a representation of the average exudation through the capillary walls in twenty-four hours, and I have thought it right to treble it, so as to have a decided over-statement of its probable quantity. We thus get 90 lbs. a day, or about 40 litres. Now if oxygen leaves the blood and passes into the tissues, it is evident that it must pass in solution in this 40 litres of exudate. How much oxygen could possibly be dissolved by this 40 litres? There is every reason to believe that the exudate does not differ materially from liquor-sanguinis in composition, and we have before seen that liquor-sanguinis is about equal to water in its power of dissolving oxygen. 40 litres of water would dissolve less than two grammes of oxygen; and this quantity of oxygen, whether it were employed in the oxidation of muscle, of fat, or of sugar, could not yield as much as 3000 metre-kilogrammes† of force. But it may be urged that, though unlikely, it is still possible that the exuding fluid may be able to carry with it a larger proportion of oxygen than this. Be it so. Let us make the absurd assumption that every hundred volumes of exudate contains more oxygen than the arterial corpuscles themselves do, when saturated with the gas. If each hundred volumes of exudate contained forty volumes of oxygen, 40 litres would still only contain about 23 grammes, and this, in uniting with oxidizable materials, could only yield about 30,000 metre-kilogrammes of force.

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* Some of these arguments were suggested to me by Dr. Marcet, F.R.S., who has studied the bearings of dialysis on pathology with great care and success.

† A metre-kilogramme is the force required to raise one kilogramme one metre. It is equal to about 7¼ foot-pounds, and is now almost universally employed as the measure of force.

Now the daily work of the heart alone is estimated by Donders at 86,000 metre-kilogrammes, and it is an extreme under-statement to assert that the total daily work of the body in health is 100,000 metre-kilogrammes. To do even this quantity of work, twice the quantity, or 200,000 metre-kilogrammes of force must, as Heidenhain has proved, be provided; so that even taking the highest possible calculation of the quantity of oxygen which could pass into the tissues, we see that it cannot account for one-sixth of the work done in them. It is more probable, indeed, that it cannot account for one-sixtieth. To supply the minimum force per diem exerted in the body, there must be a daily exudation of about

264 litres, or ¼-ton, if the exudate contains as much oxygen as arterial corpuscles; or,
3500 litres, or 3½-tons, on the more probable supposition that it will not dissolve more than water will.

These figures appears to me to furnish a complete answer to the current theory of tissue-oxidation, and to force us inevitably to the conclusion so clearly pointed out by Mayer, namely, that the whole, or nearly the whole, of the animal oxidation, is effected in the blood itself, and consequently that there must exist some provision by which chemical force set free inside a capillary is converted into mechanical work in the tissues outside of it.

This view of the nature of animal oxidation tends to define more clearly our knowledge of the functions of the blood. Nutrition is one of its functions. It carries with it in its course the appropriate *pabulum* for the repair of all the tissues of the body. Bones, nerves, glands, and muscles, all alike reproduce their elementary parts at the expense of material derived from its fertilizing stream. And as these elementary parts attain their term of life they decompose and liquefy, passing again into the blood, for the most part through the same lymphatic vessels which take back the excess of the nutritive fluid. In the lymphatic vessels and glands much of the lymph is once more organized into blood, but the products of the disintegration of tissue are probably incapable of this renewal, and, in the absence of evidence must be supposed to return into the blood in an unorganized condition.

Equally important with the foregoing is the function of oxidation, to which the force as well as the heat of the body is due. Nitrogenous as well as non-nitrogenous bodies are oxidized in the blood, and though we do not yet know the precise conditions or the precise mode in which the oxidation is effected, we are justified in inferring that it is by the direct agency of the corpuscles. There is on this view no ground for the assumption that either force or heat is due exclusively to the oxidation of one or the other class of organic compounds. Both are oxidized, and one is as likely as the other to be the motive power. Even the muscle itself, inasmuch as it is finally oxidized in the blood, may give rise to muscular work, and we must therefore conclude that Traube's hypothesis is as much an over-statement on the one side as Liebig's was on the other.

The changes effected by the blood in the exercise of its functions are subject, to a most remarkable extent, to the control of the nerves; and little as we know of this the most obscure region of physiology, we cannot avoid the conclusion that they are directly concerned in the transformation of chemical force into mechanical effect. The muscular currents of electricity, which have been so carefully studied by Du Bois-Reymond, Helmholtz, Heidenhain, and many others, are, no doubt, closely connected with this conversion; but I will abstain from speculations which are apt to degenerate into bare guesses. Dim foreshadowings of great discoveries lie before us, and it is better, after clearly stating to ourselves the truths already established, or made probable, to wait with humility, watching till diligent and patient search shall have been rewarded with fresh unveilings. If we can clear a point or two in the intricate forest of knowledge which lies before us, we shall have done truer work than by any amount of speculation.